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Life cycle economic analysis of fuel ethanol derived from cassava in southwest China

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Abstract

For energy security and environmental improvement reasons, the Chinese government is developing biomass ethanol as one of its transportation fuels. Cassava is a good feedstock to produce this ethanol because it has a high starch content and it is abundant in the southern provinces. A computer-based cost model has been developed to assess the life cycle economics of ethanol produced from cassava. The results are compared to gasoline as a base-line case. Although ethanol fuel is not currently competitive with conventional gasoline, these life cycle cost results indicate that, at present market prices, ethanol has the potential to be competitive if there are incentives and improved cassava yields. In addition, this renewable energy could help to alleviate poverty, improve land utilization and bring energy independence in Guangxi province in southeast China. This computer model will be an important tool for the energy policy makers to understand whether an energy alternative is cost-competitive, as well as providing a way to find appropriate measures throughout the entire life cycle that optimizes the process and removes the economic barriers.

Keywords: Life cycle assessment; Cassava; Fuel ethanol; Economic analysis

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Contents

1. Introduction

China has been a net importer of petroleum since 1993. At present the amount imported is about 25% of the total demand [1]. By 2005, 2010, and 2015, the numbers could be 36, 43, and more than 50%, respectively [2,3]. Also, the combustion of petroleum products contributes greatly to air pollution, especially in the metropolitan areas where the exhaust emissions from vehicles has become one of the main pollutant sources [4]. The use of fuel ethanol could help to reduce some of these emissions. Therefore, developing a domestic renewable energy to shrink oil imports would have strategic significance for the energy security of China, as well as contributing to environmental improvement.

Currently, fuel ethanol is produced almost exclusively form cornstarch, but cassava has a very high starch content, up to 32%. In south China, the cost of the cassava is less than that of corn because the cassava is growing on marginal lands where other agricultural crops such as rice, wheat, corn, and sugarcane cannot be grown. Since the cost of the raw materials accounts for more than half of the total cost of ethanol production [5], cassava would be a good feedstock option for producing ethanol. The Chinese central government is promoting the development of ethanol

from biomass as an alternative to conventional petroleum transportation fuels. Guangxi Zhuang Autonomous Region in southwest China, with the highest concentration of cassava cultivation, is promoting the development of cassava as a path for economic growth in the region.

If fuel ethanol were practical, vehicle drivers would readily accept its use. That means the retail price would be no more than that of gasoline and the use of ethanol would not increase the cost of vehicle operation. Moreover, the use of ethanol as a fuel must be beneficial for all of the stakeholders, not just some of them. Therefore, the economic assessment of ethanol as a fuel should include more than just the conversion cost. Feedstock cultivation, transport, refueling and final use must be included as well. In other words, all of segments of the entire life cycle must be investigated.

Based on this need, a cost model of the ethanol life cycle was developed, with the goal of comparing the economics of an ethanol fuel system to its functionally equivalent gasoline counterpart. The term ‘ethanol fuel system’ includes not only the ethanol, but also the vehicle and the industrial infrastructure required to build, maintain, and refuel it.

2. Methodology

The economic analysis was conducted by life cycle costing (LCC) of the ethanol fuel system. The scope of the study includes the cassava plantation, the conversion to ethanol, the distribution of the fuel, the purchase of the vehicle and the fuel, the refueling infrastructure, and the operation, maintenance and repair of the vehicle. The key processes are summarized in the flow chart of Fig. 1. A lifetime driving distance of 120,000 miles was used for both the ethanol and gasoline base case.

2.1. Model establishment

The cost model is a set of computer-based Excel spreadsheets, which establish the path of the ethanol life cycle from cradle to grave (cassava plantation to combustion in the engine). It consists of 15 spreadsheets, one of which is shown in Fig. 2. At each stage in the model, the costs include materials, energy (electricity and/or steam), labor, transportation, depreciation of fixed assets, maintenance, and miscellaneous costs, which are positive values, and the value of the co-products such as CO_2, DDGS, and manure, which are negative in the calculation. Biogas from the anaerobic treatment is combusted in the boiler to generate electricity, as well as steam for the ethanol plant. Tax, land rent, and profit margin were added to the cost. The final cost of the fuel ethanol is an aggregation of all of the various process costs and values, both positive and negative.

2.2. Data collection

The amount of economic data related to the ethanol life cycle is huge. The data collection was difficult and time consuming. A significant part of the data was

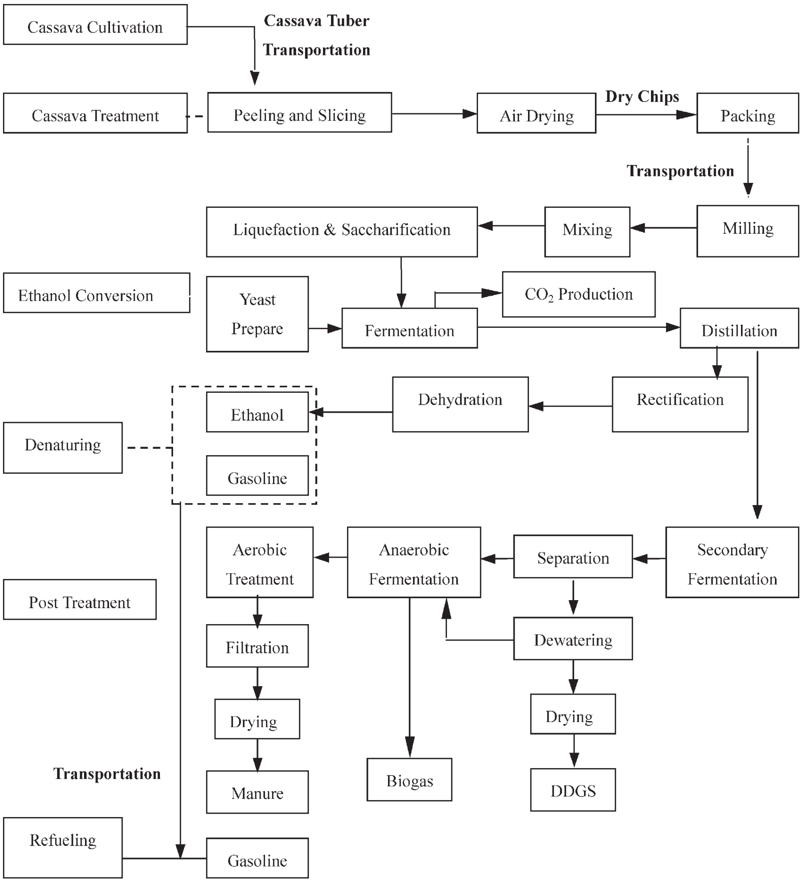

Fig. 1. Life cycle of fuel ethanol from cassava.

obtained through on-site collecting in the Guangxi region. Equipment costs were obtained from vendor quotations whenever possible. The variable operating costs, such as the cost of chemicals in the various processes, are based on the present operating costs. The price of the electricity and water for industrial use was assumed to be the same as the current prices in Guangxi.

An ethanol plant with an annual capacity of 33.4 million gallons of denatured ethanol (95% by volume anhydrous ethanol and 5% by volume gasoline) needs about 780,000 tons of fresh cassava tubers as feedstock, which requires at least 20,000 hectares of cassava plantation. This crop yield is based on many years of successful large-scale cassava farming in Guangxi.

The cost of cassava cultivation includes the purchase of seeds and chemicals, land tax, labor costs, tuber collection and residues transportation.

At the ethanol plant, the cost includes purchase and transport of dry chips, auxiliary materials, labor, and supplementary electricity use, minus the co-product credits

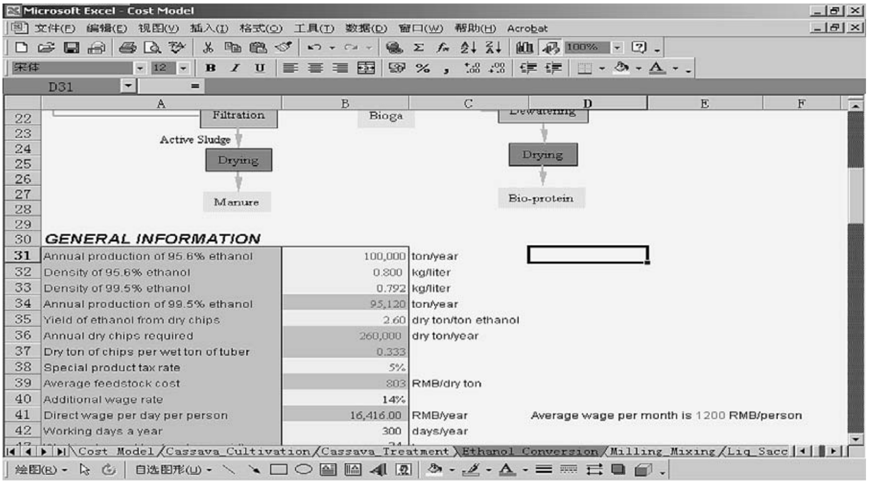

Fig. 2. One of cost model spreadsheets.

for CO_2, DDGS, and manure. A process flow sheet with mass balances was developed in order to distribute the costs and benefits of each process step. A simplified mass balance for ethanol conversion is shown in Fig. 3.

DDGS and manure are sold to farmers, while the biogas is collected and stored for use in the plant itself. The biogas is burned in the boilers to provide steam for use in the plant and to generate electricity. The water in the last post treatment step is partially recirculated for anaerobic and aerobic digestions, with the remaining residue water released directly.

The utilities such as steam, cooling tower water, and some of the electricity are self-supplied in the cost model, but the cost of the equipment required for their generation is included in the capital cost of the facility.

The ethanol was denatured with gasoline at the plant, before distribution to the refueling station so the gasoline price was assumed to be at the gate of the ethanol plant. The retail price of ethanol fuel is determined by its cost and fuel tax of 14.3% in China.

The purchase price of the vehicle which operates on E10 (10% by volume fuel ethanol added to gasoline) was assumed to be the same as the vehicle that operates on conventional gasoline. The overall operating costs include the purchase price of the vehicle and the fuel, and the vehicle maintenance/repair costs.

3. Results

The data collected were used as input to the cost model. The costs of the fresh tubers and dry chips are in US dollars (USD) per ton, while the costs of anhydrous ethanol, denatured ethanol, and E10 are in USD per gallon. These costs are discussed in more detail below.

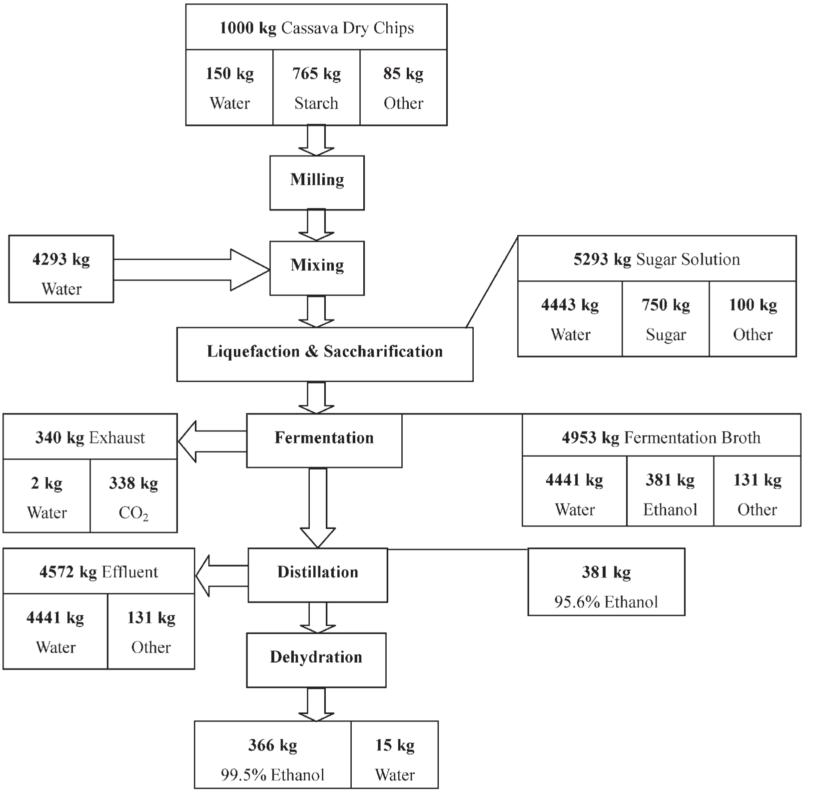

Fig. 3. Simplified mass balance for ethanol conversion.

3.1. Cost of cassava

The price of cassava tubers varies from year to year, but in the last few years it has ranged from $24.10 to $27.71 per ton. The breakdown of the various elements that add to the final tuber cost as a percentage of the total is shown in Fig. 4. The cost of the fresh tubers was calculated to be $13.62/ton, but the final price is based on inclusion of profit margin, income tax, etc.

The cost of the dry cassava chips comes from the cost of the fresh tubers, transportation of the tubers and the processing cost. It requires three tons of tubers to make one ton of dry chips. The final cost of the dry chips is $42.81/ton; 95% of this cost is the cost of the tubers and 4% is the cost of the processing. But the price on the open market is $86.75 per ton after adding profit margin, taxes, etc.

3.2. Cost of ethanol

The feedstock cost of ethanol conversion is the sum of the cassava and its special tax, as well as the cassava transport cost. These are $86.75 per ton for the dry chips,

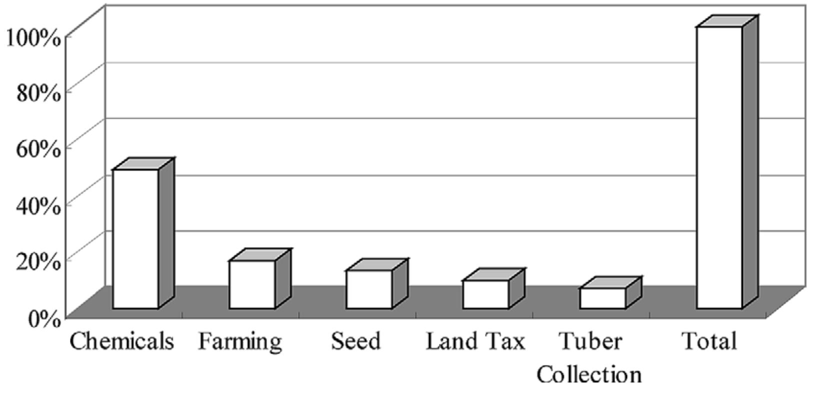

Fig. 4. Breakdown of total tuber cost.

5% of special product tax, and $5.66 per ton of transport cost, respectively, for a total cost of feedstock of $96.75 per ton. This brings the cost for a gallon of ethanol to $0.75. The detailed cost elements of ethanol production are listed in Table 1. The production costs for each process step are shown in Fig. 5.

The traditional co-product in a dry milling facility is DDGS. In this study, other co-products are the CO_2 from the fermentation step, biogas, and manure from the post treatment step. Their contributions to the economics of ethanol are shown in Table 2. If the profit margin is set to 8%, as it was in this model, the final wholesale price of the neat (99.5%) ethanol at the plant is $1.30 per gallon, including tax.

3.3. Retail price of the fuels

At the refueling station, the retailer gets denatured ethanol and conventional gasoline for $1.35 per gallon and $1.00 per gallon, respectively. Because of the difference in the volumetric energy density, on an equivalent energy basis these prices are

Table 1
Detailed cost elements of ethanol production

	$/gallon
Materials cost	0.76
Energy cost	0.05
Wage and addition	0.02
Depreciation	0.06
Maintenance cost	0.04
Miscellaneous costs	0.01
Fiscal charges	0.05
Land rent expenses	0.001
Selling expenses	0.01
Total cost	1.01

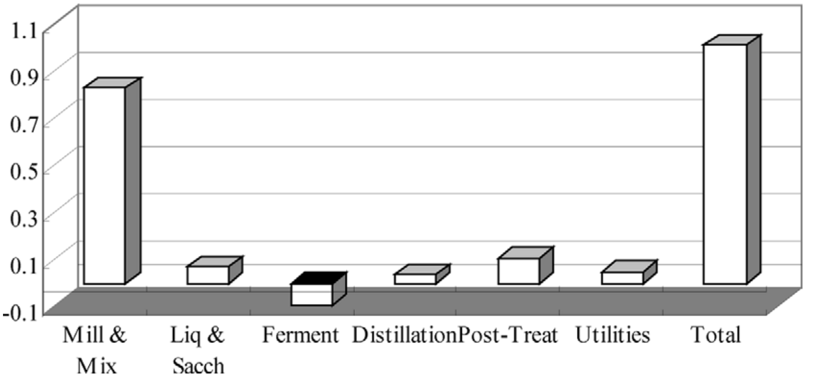

Fig. 5. Production costs for each process step ($/gal.).

Table 2
Co-products contribution to one gallon of ethanol

CO_2	$0.29
DDGS	$0.01
Biogas	$0.04
Manure	$0.11

$17.31 per mmBtu (million Btu) and $8.69 per mmBtu, respectively. So operation of the vehicle on ethanol would cost the customer twice as much as conventional gasoline. If the ethanol is used to make E10, the economics become more feasible. After tax is added, along with the 10% profit margin of the retailer, the final price of the conventional gasoline is $1.19 per gallon. For E10, the final price is $1.24 per gallon.

3.4. *Cost of vehicle operation*

The fuel economy of the conventional gasoline vehicle was assumed to be 29.6 miles per gallon (mpg). Because of the lower energy content of the E10, the fuel economy of the vehicle operating on E10 would be 28.7 mpg (assuming operation was controlled at the same air-fuel ratio). Therefore, assuming the same repair and maintenance costs for both vehicles, the cost of vehicle operation on E10 and conventional gasoline would be $4.32 and $4.03 per 100 miles, respectively.

4. Discussion

Based on the results given above, operation of the vehicle on neat ethanol is not economically feasible since the cost of the fuel would be 40% more for the vehicle operator compared to gasoline. The alternative is to use the ethanol as an oxygenate and an octane enhancer to make E10.

Denatured ethanol (5% by volume gasoline and 95% by volume ethanol) is produced at the ethanol plant at a cost of $12.98 per mmBtu. When profit margin and fuel tax are added, the wholesale price of the denatured ethanol goes up to $16.73 per mmBtu. This makes the price of E10 at the retail refueling station $11.08 per mmBtu, including the retailer's profit margin and tax, which is almost 8% higher than the price of the gasoline at $10.30 per mmBtu. Therefore, in order for the E10 to be an acceptable alternative fuel, the cost of the ethanol needs to be reduced.

Fig. 6 shows the cost of the various components of the ethanol production. It can be seen that the cassava production dominates the final cost. Also, by analyzing the entire life cycle of the ethanol production, some key factors were identified that have a significant impact on the price of the ethanol and its competition with gasoline.

4.1. Cassava production

Fig. 6 shows the cost of cassava to be about 70% of the cost of the ethanol. Historically, the price of cassava dry chips has been fluctuating between $77 and $110 per ton. In order to compete with gasoline, the price of the dry chips needs to be $74 per ton or less.

Increasing the cassava crop yield is one approach to reduction of cost. Fig. 4 shows that the cost of chemicals comprises 49% of the cost of the cassava tuber, so selecting more effective chemicals or using self-supplied manure could reduce the tuber cost. In recent years, research to optimize the seed has been the main focus for enhancement of the cassava yield. The cost of the seed and farming is 17% of the tuber cost.

In order for neat ethanol fuel to be competitive, the cassava crop yield would need to be 94 tons per hectare which does not appear technically feasible at present. For E10 to be competitive, the crop yield needs to be about 68 tons per hectare. So far, the farming experts in China have increased the cassava yield from 30 tons per hectare to 45 tons per hectare, and it is believed this can be increased still further

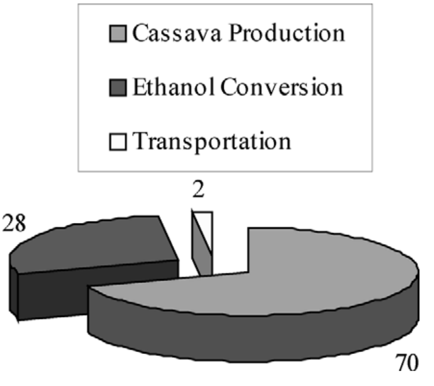

Fig. 6. Components costs of ethanol production (%).

under specific conditions to 60 tons per hectare, but this is still short of the crop yield needed for prices to be competitive with gasoline.

4.2. Co-products

Three co-products can have a substantial impact on the economics of ethanol production. An ethanol plant can capture and sell the CO_2, but a CO_2 consumer must be nearby, and the amount of CO_2 generated must be great enough to justify the cost of recovery and purification equipment for cleaning and pressurizing it. DDGS is 27% protein and is currently sold as animal feed. It also could be approved for human food manufacture in the future which would increase its value and demand. The manure produced in the ethanol plant is the remnant of the total solid matter in the effluent from the distillation column after the DDGS is removed. The manure can be sold to the farmers for growing the cassava. In general, it contributes about 25% of the total co-product sales.

The value of these three co-products can be more than 1/3 of the total cost of the ethanol as shown in Table 2. For purposes of this study the value of the three co-products was estimated based on recent market prices, but it is believed these are conservative figures. The price of the DDGS was assumed to be the most stable because it makes the least contribution to the total. Therefore, a sensitivity analysis was made by varying the price of the CO_2 and manure. When the prices of the CO_2 and manure increase by 30%, the ethanol cost goes down to \$0.89 per gallon; when the prices decrease by 30%, the ethanol cost goes up to \$1.13 per gallon. Also, it is apparent from Fig. 7 that the CO_2 has a stronger impact on the ethanol cost compared to the manure.

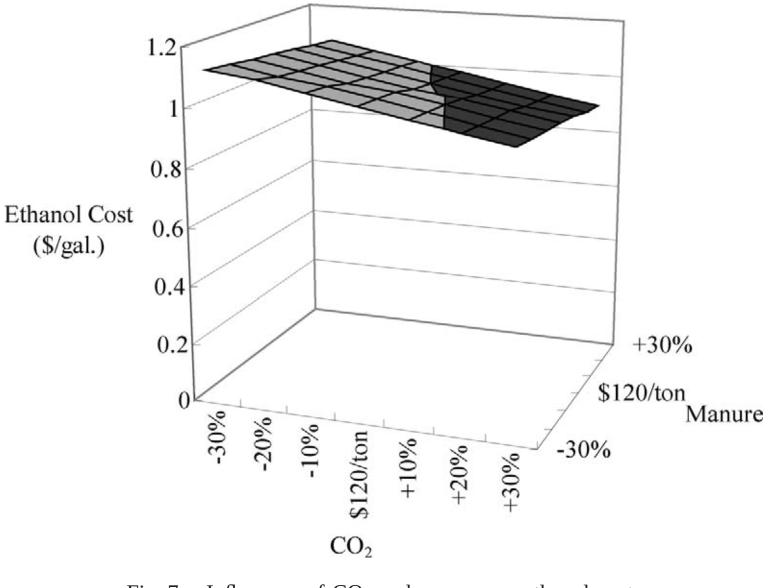

Fig. 7. Influences of CO_2 and manure on ethanol cost.

4.3. Gasoline price impact

Obviously, an increase in the wholesale price of gasoline would narrow the retail price gap between E10 and gasoline the most since 90% of the E10 volume comes from gasoline. It appears as if the retail price of E10 would be the same as that of gasoline if the gasoline wholesale price were 110% of the presently assumed price, but in fact, as oil prices go up, the price of chemicals would rise also. Therefore, since 49% of the cost of the cassava tuber is the cost of the chemicals, the gap could actually get wider with an increase in the price of crude oil.

4.4. Profit margin

The profit margin assumed in the production of the ethanol was 8%. It was also assumed that the oil industry would engage in the production of the fuel ethanol. Since the ethanol content of E10 is only 10% by volume, the profit margin of the ethanol makes less of an impact on the final price of E10 compared to denatured ethanol. In this study, the profit margin assumed for the retail price of both E10 and gasoline was 10%. If the gasoline profit margin is fixed at 10%, but the profit margin of the E10 is allowed to fluctuate, the retail price of E10 is competitive with gasoline when its profit margin is 4.6% as shown in Fig. 8. At this point, the cost of operation of the vehicle is the same for both fuels.

4.5. Tax

Tax can have a significant influence on whether E10 can compete economically with gasoline. Since the tax is controlled by the government, this is a feasible approach that could be used to make the price of E10 competitive with that of gasoline.

Based on the lower heat value, the retail price of a gallon of E10 should be 97% of that of a gallon of gasoline. Drivers would then avoid any additional expense for

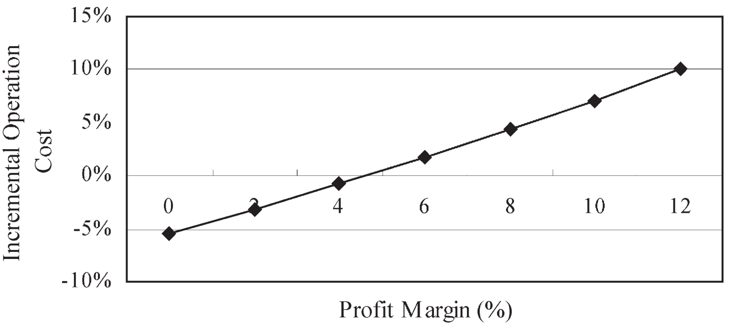

Fig. 8. Influence of profit margin of E10 retail on drivers.

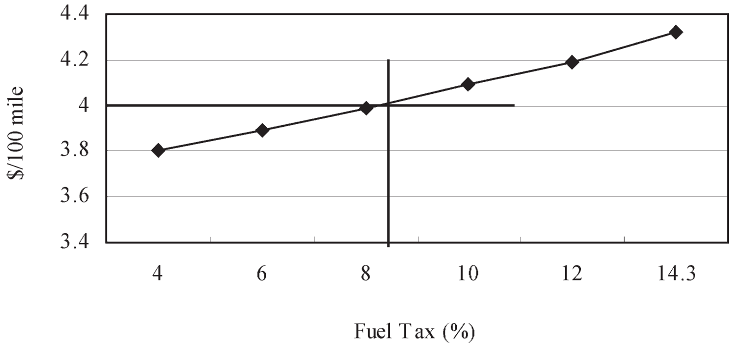

Fig. 9. Tax impact on cost of vehicle operation.

fuel and they would feel free to use E10. Fig. 9 shows, if the tax on E10 is allowed to vary, when it is 8.2% or lower, the operation cost of the E10 vehicle would be competitive with that of the conventional gasoline vehicle.

4.6. Local economic growth

For an ethanol program with an annual capacity of 33.4 million gallons of denatured ethanol, the total subsidy would be $20.4 million (USD). But the farmers could make a profit of $11.4 million from cassava cultivation, the ethanol producer could make a profit of $3.2 million, and the fuel seller could make a profit of $3.9 million. The government would get a tax of $1.1 million from the farming land, a special tax of $1.1 million when the cassava was sold, a tax of $4.1 million from the ethanol producer, and a tax of $1.8 million from the fuel ethanol retailer. This is summarized in Table 3. As can be seen, the sum of the profits and taxes is $26.6 million, which is much more than the subsidy.

In addition, this fuel ethanol program would make 200,000 hectares of land arable—land that is not suitable for regular crops. There would be a nice way for Karst (lime rock) topography in this region. And the cassava cultivation would promote employment for about 60,000 farmers in Guangxi.

Table 3
Subsidy and profits and taxes for the program (USD)

	Cassava production	Ethanol production	Fuel ethanol retail
Tax	2,212,000	5,923,000	5,608,000
Profit	11,424,000	3,314,000	3,921,000
Sub-total	13,636,000	9,237,000	9,529,000
Total	32,402,000		
Subsidy	21,150,000		

4.7. Government incentives

It is clear from the above calculations that the government needs to provide an incentive to the fuel ethanol industries in order to make E10 economically competitive with conventional gasoline. Since the Chinese central government is implementing the 'Western China Development' program, which includes the Guangxi Zhuang Autonomous Region in the southwest, it should be possible for the fuel ethanol industries to get a tax exemption or subsidy from the central government. The subsidy for the fuel ethanol seller would be $0.05 per gallon for E10, or $0.67 per gallon for fuel ethanol.

Since Table 3 shows the sum of the profits and taxes is larger than the government subsidy, it is instructive to try to balance the two. If the profits of the farmer, the ethanol producer, and fuel retailer, and the taxes from the farming land and E10 retailer are held invariable, the government could give a tax incentive to the ethanol producer and retailers. Under this scenario, the ethanol producer would actually get a tax exemption and the retailer could get a tax credit of $0.17 per gallon or 95% of its ethanol tax. In reality, the entire subsidy is given to the farmers as their profits.

5. Conclusions

With the use of the systematic cost model, an economic analysis of the product life cycle was performed. The details of the cost components and key points of the analysis are given in the Figures and Tables. The case study of fuel ethanol gave the following conclusions:

1. Because of its high price, neat ethanol is not feasible as an automotive fuel at this time. The operation cost of the neat ethanol-fueled vehicle would be unacceptable compared to gasoline.
2. E10 could be an alternative fuel for the vehicle. Seventy percent of the cost of the ethanol depends on the price of the cassava. If the cassava price goes down, E10 is a possible alternative to MTBE as an octane booster and oxygenate in gasoline.
3. If the cassava crop yield is enhanced and development of the co-products optimized, the ethanol cost would improve and could become competitive with conventional gasoline.
4. Government incentives could play an important role in the use of fuel ethanol. If the fuel tax on E10 were reduced to 8.2% from the present 14.3%, the operation cost of the E10 vehicle would be equal to that of the conventional gasoline vehicle. All of the subsidy can be loaded on the farmers as their profit.
5. The profit margin of the ethanol production would influence the cost of the denatured ethanol and the retail price of E10. If the oil industry produces the ethanol, the retail price of E10 would be lower and it could be cost-competitive.
6. Even though a subsidy is needed at present, there are other economic benefits to this ethanol program. The cassava plantation of 200,000 hectares would improve

utilization of the land and provide employment for the farmers. An annual production of 31.7 million gallons of fuel ethanol would reduce gasoline consumption by 21.9 million gallons and hence reduce dependence on crude oil. It is believed that this renewable energy is sustainable in Guangxi.

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